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Feasibility study of green wastes composting with digested and dewatering sludge from municipal wastewater treatment plant in Iran

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Abstract

Background: Composting as a waste management technology is becoming more widespread. The purpose of this study was to assess the feasibility and to find the most effective composting process for the ratio of green waste, digested and dewatered sludge from Chonibieh wastewater treatment plant in the west region of Ahvaz.

Methods: The composting time was 23 days and the evaluated parameters in this period of the study were organic carbon, total nitrogen, phosphorus, carbon to nitrogen ratio (C/N), moisture content and pH. The C/N ratio was maintained at 30 with weight:weight ratio of 1:1, 1:2, 1:3 (digested and dewatered sludge to green waste).

Results: It was observed that vessel R3 produced higher quality of compost with final total nitrogen (1.28%), final total phosphorus (0.71%), final total organic carbon (TOC) (25.78%) and C/N (20.65%) within the 23 days of composting. While vessel R1 produced higher final total nitrogen and total phosphorus with lower amount of total coliform indicating suitable quality of composting. Therefore, the results showed that the characteristics of dewatered sludge mixed with green waste proportion of green waste significantly influenced the compost quality and process dynamics. The results also showed that the quality of final products in all the conditions was in agreement with Global Organic Textile Standard (GOTS) and World Health Organization (WHO) guidelines. However, the moisture content ratios were lower than the mentioned guidelines. With regards to microbial quality, all three ratios were in agreement with US Environmental Protection Agency (EPA) and Iranian guidelines.

Conclusion: It is suggested that the final product of composting can be safely used in farmland and green space.

Keywords: Composting, Septic sludge, Dewatered sludge, Green waste

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Introduction

In Iran, more than 80% of agricultural land is arid and semi-arid with poor organic material in their soil. Adding organic matter is essential to improve the fertility of agricultural soils. The composting process is a practical method for achieving this goal. Composting of garden waste and sewage sludge is an effective method for the production of stable material that can be used as a source of nutrients in the soil (1).

Composting is a controlled process of microbial decomposition, oxidation of heterogeneous mass of organic matter. This process of degradation of organic material is intermediated by microorganisms decomposers, therefore, the process is influenced by optimal conditions of moisture, aeration, temperature, carbon to nitrogen (C/N) ratio, and pH (2).

The treatment process and disposal of sewage sludge are considered as a complicated issue for wastewater treatment experts (3). Although the quantity of producing sludge is near to 1% of the total treated sewage in wastewater treatment plants; its treatment costs meet 40% to 50% of the total treatment costs. Moreover, its treatment needs complex equipment and the long time usage from one week to several weeks (4).

Green wastes may result from gardening, landscaping and agriculture activities, such as planting, pruning, lawn mowers and cutting off the extra stem and foliage. Leaves, grasses, herb fines and foliage cuts are usually considered as the most common raw materials for composting of gardening and green wastes (5).

Composting process is a type of post-treatment of waste and may be an economical process of post-treatment. In comparison with other processes of post-treatment, composting process is a more economical process (6). Municipal sludge usually has 18% to 35% solids depending on the type of dewatering method (65% to 82% moisture). These sludge cakes have higher moisture content, so its composting in order to reduce the moisture content would be difficult. However, it can be mixed with a dry bulking agent (7). Using bulking agents have some advantages, such as reducing the moisture content, NH_3 and greenhouse gas emissions, control of initial C/N ratio and aeration. So, adding bulking agents would be an acceptable practice (8). Bulking agents, such as sawdust, wood chips, and leaves have higher carbon content which can be added to compost in order to create C/N ratio in balance, increase mixture porosity and increase the resulted aeration. Carbon and nitrogen are considered as 2 essential energy sources for microorganisms. In sewage sludge, C/N ratio ranges usually from 20:1 to 40:1; so, microbial growth requires additional source of biodegradable carbon with ratios lower than 25:1. Bulking agent and added carbon source can supply additional carbon and improve C/N ratio and energy balance (9). Moreover, composting of bulking agent and sludge would be considered as a safe method to produce humic substances during composting process and reduce odor emission (1).

Several studies (5,10-24) were conducted to evaluate the effects of type and amount of bulking agents in sludge composting to find the most suitable ratio of sludge/bulking agent. However, further studies are needed for better understanding of composting processes. Therefore, this study aimed to evaluate the feasibility of producing usable compost from digested and dewatered sludge and green waste as bulking agents in Ahvaz, Iran.

Methods

In this study, digested and dewatered sewage sludge, passing through filter press, digestion and sludge drying beds, were obtained from wastewater treatment plant in the West of Ahvaz. The composting was carried out in Ahvaz Jundishapur University of Medical Sciences in an uncovered composting pilot scale unit. The harvested wastes from green space were used as a bulking agent. Table 1 shows the main characteristics of composted wastes. Three series of composting vessels were prepared by mixing sludge with green wastes in different weight ratios of bulking agent to sludge (1:1 in vessel R1; 1:2 in vessel R2 and 1:3 in vessel R3). Table 2 shows the features of vessels, sludge and bulking agent. The baseline for composting was defined as the day when all the vessels were completely formed. Vessels with cylinder shape were placed in pilot scale units, which were not sheltered from the rain and sunlight. The sludge was dried under direct sunlight for 7 days and entered into the composting process. Green waste (a mixture of grasses, plants, leaves, branches and roots from the university green space area) was dried and crushed in 7 to 10 cm and then used as a bulking agent. Then, sludge and green wastes were mixed together and poured into vessels. The composting procedure was carried out in 23 days. All vessels were weekly turned over with no other forced aeration provided. To maintain sufficient and adequate water content in compost process, the vessels were periodically monitored and water content was determined by laboratory analysis. Then more water was added when its content was insufficient.

The basic principle for the quantitation of total organic carbon (TOC) relies on the destruction of organic matter present in the compost. The destruction of the organic matter can be performed chemically or via heat at elevated temperatures (25). In this study, combustion method was used to determine the TOC (26). After the weighted 2 g of the sample was dewatered in oven at 105°C for 24 hours. Then, it was weighted again (weight A). Dried sample was burned in 550°C and weighted (weight B). TOC was quantified using this equation (Equation 1).

Table 1. The main characteristics of composted wastes

Material	Moisture content (%)	Total coliform[b]	Fecal coliform[b]	Organic C (db, %)	Total phosphorus (db,%)	Total N (db, %)	C/N	pH
Sludge	15.3	28×10^{16}	28×10^{16}	27.85	0.48	1.084	N/M	N/M
Bulking agent	1.84	9×10^{7}	9×10^{7}	40.95	0.31	1.22	N/M	N/M
R1[a]	20.2	N/M	N/M	27.17	0.67	0.91	30	6
R2[a]	18.2	N/M	N/M	26.6	0.31	0.87	30	6
R3[a]	21	N/M	N/M	26.43	0.71	0.88	30	6

Abbreviations: N/M, not measured; C/N, carbon to nitrogen; MPN, most probable number.

[a] Properties determined once the vessel was built.

[b] MPN/g of total dry solids.

Table 2. Features of vessels, sludge and bulking agent

Material	Bulking agent (w/w[a], kg)	Sludge (w/w, kg)
Vessel R1	1.850	1.850
Vessel R2	1.100	2.200
Vessel R3	0.850	2.550

[a] w/w: wet weight.

TOC = ((A-B)/A)×100

To determine the total Kjeldahl nitrogen, Kjeltec Analyser unit 2300 was used. A test portion of the dried and grinded sample of about 0.5 g was placed in the digestion flask. 10 ml sulfuric acid was added and swirl until the acid was thoroughly mixed with the sample. The mixture was allowed to stand for cooling. Then, 2.5 g of catalyst mixture was added and heated until the digestion mixture became clear. The mixture was gently boiled for up to 5 hours so that the sulfuric acid would condensed to about 1/3 of the way up to the neck of the flask. It must be ensured that the temperature of the solution does not exceed 400°C. After completion of the digestion step, the flask was allowed to cool and 20 ml of water was slowly added while shaking. Then the flask was swirled to bring any insoluble material into suspension and transfer the contents to the distillation apparatus. The flask was rinsed three times with water to complete the transfer (27).The percentage of total nitrogen of the samples was shown by apparatus.

Total phosphorus was determined by stannous chloride method once a week (27). The acid-dried soil was dried to a fine powder and 0.5 g of it was weighed in round-bottomed flask. 2 ml each of concentrated nitric and perchloric acid were added to the sample. The flask was heated till the content became dry. Then 2 ml of sulphuric acid was added and heated for 15 minutes. The digested content was filtered through Whatman No. 44 filter paper and the filtrate was made up to 250 ml with distilled water. The phosphorus content of the filtrate was determined by adding 4 ml of ammonium molybdate solution.

In order to determine the pH, 5 g of the sample was stirred in 50 ml distilled water and pH was measured using a digital pH meter with a glass electrode, previously calibrated and corrected for temperature (28).

The moisture content (4) was measured once every 3 days and was determined by drying a moist sample (10 g/wet weight) in an oven that was set at 105°C until constant sample weight and expressed on a wet weight basis.

Total coliform and fecal coliform were determined once a week using the multiple-tube fermentation direct test (29). One gram of the compost material sample was mixed with 100 ml of sterile water and was blended for 40 seconds in a sterile stainless-steel blender at low speed. Dilution of the slurry was made and 10 ml of the dilutions was added to lactose broth medium. Tube contents were incubated at 37°C for 3 hours, small bubbles were removed, and the materials were again incubated at 44.5°C for 21 hours before results were recorded. Gas in the inverted Durham tube and turbidity of the medium indicated positive results, and the most probable number (MPN) was estimated using an MPN table (30).

Statistical analysis

The statistical analysis was done by SPSS version 16 using variance analysis and correlation coefficients. $P < 0.05$ was considered as significant.

Results

Initial and final features of the composting mixtures are shown in Tables 1 and 3, respectively. Figure 1 shows the evolution of moisture based on wet weight during composting process. The water content was determined once in 3 days and was checked and controlled to maintain vessels moisture in suitable level according to standard limits. The dewatered sludge was very low in water content, so more water was added to raise the vessels manually up to World Health Organization (WHO) limits for composting.

Figure 2 shows the trends for pH in vessels. With regards to R1, there was an increasing trend with slight reduction on day 19. Maximum pH value of 7.5, 7 and 7 was ob-

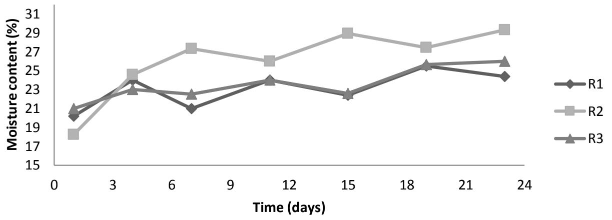

Figure 1. Evolution of moisture based on wet weight during composting process for vessels R1, R2 and R3.

Table 3. Properties of the final products obtained from the three composting experiments (Mean values ± standard deviation).

Material	Moisture content (%)	Total coliform	Fecal coliform	Organic C (db, %)	Total phosphorus (db, %)	Kjeldal N (db, %)	C/N	pH
R1	21.22 ± 1.42	15×10^{17}[a] 120[b]	20×10^{17} 168[b]	24.01 ± 5.03	0.67 ± 0.01	1.96 ± 0.032	13.8	7 ± 0.48
R2	24.03 ± 2.01	21×10^{17}[a] 157[b]	21×10^{17} 190[b]	25.02 ± 2.31	0.31 ± 0.05	1.49 ± 0.06	17.9	6 ± 0.39
R3	25.1 ± 3.47	150×10^{17}[a] 978[b]	93×10^{17} 569[b]	25.78 ± 0.93	0.71 ± 0.02	1.28 ± 0.07	20.65	6.5 ± 0.48

Abbreviations: db, Dry basis; C/N, carbon to nitrogen.

[a] MPN/100 ml.

[b] MPN/gTotaldry solid.

served on the 15th, and 11th day, which steadily decreased to 7, 7 and 6.5 after the 23 days of composting in R1, R2 and R3, respectively.

For organic carbon (Figure 3), a similar pattern was seen in all the vessels with a peak rise on day 8 and thereafter a sharp fall until day 15, followed by gradual decrease until the end of composting process (Figure 3). In this study, the overall decreasing trend for organic carbon is as follows: R1: from 27.17 to 24.01% (17.25% of reduction rate); R2: from 26.6% to 25.02% (2.5% of reduction rate) and R3: from 26.43% to 25.78% (11.63% of reduction rate).

For nitrogen content, an increasing trend was observed in all the vessels. Figure 3 shows the time course of the total nitrogen (NT) in the vessels. The overall increasing trend in this study for total nitrogen is as follows: R1: from 0.91 to 1.96% (115% rising); R2: from 0.87% to 1.49% (71.26% rising) and R3: from 0.88 to 1.28% (45.45% rising). The highest increase was observed in vessel R1.

With regards to total phosphorous, a decrease was observed in all the vessels in the pre and post composting process (Figure 4). Vessel R3 had the highest initial content of total phosphorous (0.71%) when compared with the other vessels (0.67% and 0.31% in vessels R1 and R2, respectively). No changes was found at the final phosphorous for the vessels.

The initial C/N ratio of composting materials was adjusted to about 30 and was decreased to 13.8%, 17.9% and 20.65% in vessels R1, R2 and R3, respectively at the end of the process (Figure 5), which are below the optimal C/N ratio of 25.

The MPN of the total and fecal coliforms in different stages of the composting process was in day 15 which was the highest in vessel R2 and day 8 in vessels R1 and R3 (Figures 6 and 7). The number of both total and fecal coliforms bacteria declined with time except in vessel R2. As shown in Figures 6 and 7, the highest decrease in the number of coliform occurred after the 23 days of composting in vessel R3. In vessel R2, the number of coliforms increased slightly from day 8 to day 15 of composting and thereafter it decreased until day 23.

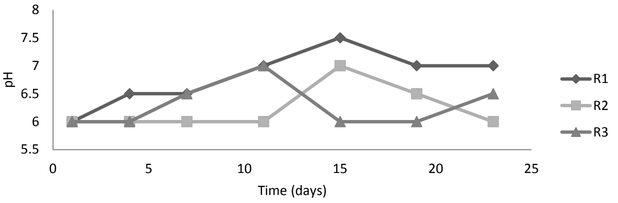

Figure 2. Evolution of pH during the composting process for vessels R1, R2 and R3.

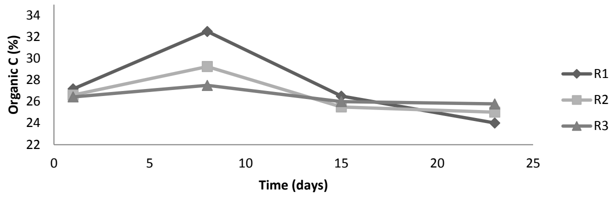

Figure 3. Changes in organic carbon during composting process in vessels R1, R2 and R3.

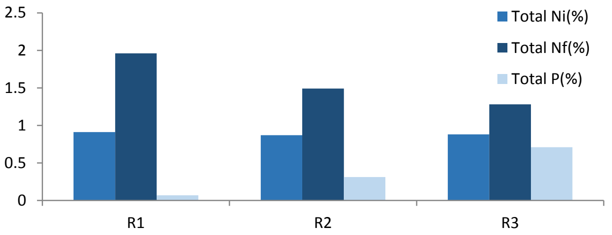

Figure 4. Changes in total nitrogen and total phosphorous during composting process in vessels R1, R2 and R3. Abbreviations: Ni, Initial in total nitrogen content; Nf, Final in total nitrogen content; TP, Total phosphorous.

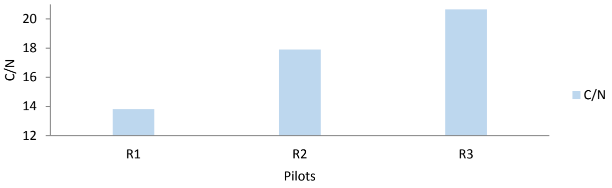

Figure 5. Changes of C/N ratio in the final product in vessels R1, R2 and R3.

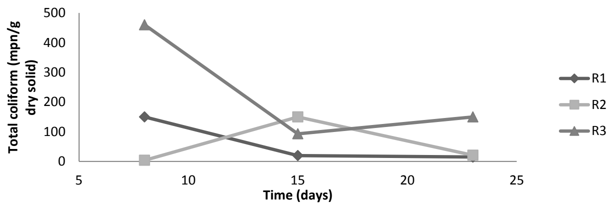

Figure 6. Total coliform number during compost process (expressed as MPN/g dry solid) in vessels R1, R2 and R3.

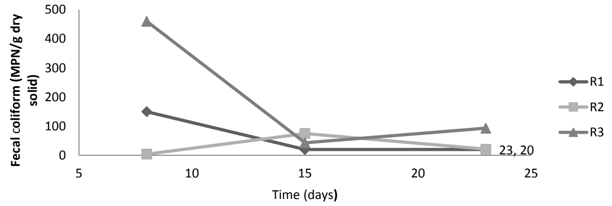

Figure 7. The fecal coliform number during compost process (expressed as MPN/g dry soild) in vessels R1, R2 and R3.

Discussion

Changes of moisture content during composting is shown in Figure 1. As shown in Figure 1, the moisture content is below the standard limitation (Table 4). Since the initial mixture of digested and dewatered sludge and bulking agent was not water-saturated, some water was added to all the mixtures. The final moisture content in all the vessels was under 40% during the composting process which is considered as the least value for the optimal composting moisture (40% to 60%). Thus, it is suggested that composting may be limited by moisture content and need further addition of water and control. It is suggested that the fluctuations observed in the overall trend were due to increase

Table 4. Physical and chemical properties of compost (WHO Standard, GOTS and Institute of Standard and Industrial Research, Iran, 2007) (1,2,22)

Parameters- unit	Acceptable limit (level 1)	Acceptable limit (level 2)
Organic matter (based on dry weight)	35%	25%
Organic carbon (based on dry weight)	Minimum 35%	Minimum 15%
Moisture %	Maximum 15%	Maximum 35%
pH	6-8	6-8
Phosphorus (Based on dry weight)	1-3.8%	3- 3.8%
Total nitrogen (N) (g/100 g)	1.25-1.66%	0.1-1.5%
C/N	20-15	15-10

in the evaporation rate that resulted from microbial activity and the aeration intervals by turning over the vessels. The decrease in moisture content may be as a result of biological degradation of organic compound in the vessels. At the end of the study, vessel R2 had the best moisture content. These results indicated that limitation in sewage composting is expected owing to the dewatering process on sludge moisture. So it is suggested that with regards to sewage sludge natural moisture content (50% to 70%), dewatered sludge should not be used for sewage composting. Digested sludge may be better option to choose. This could reduce the sludge treatment costs remarkably. In this study, higher moisture loss was observed in vessel R1 with the lowest portion of bulking agent (green waste). Higher moisture loss observed in R1 would be due to higher maximum microbial activities in this vessel. Varma and Kalamdhad (18) studied the composting of municipal solid waste mixed with cattle manure and observed higher moisture loss in trial with more microbial degradations.

Figure 2 shows the of the monitored pH of the composting material for all the vessels. Composting proceeds most efficiently at the thermophilic temperature when the pH is approximately 8 (31). Maximum pH value of 7.5 for vessel R1 was observed on day 15 (pH = 7.5). The increase in pH level at the beginning of composting is as a result of increase in the volume of ammonia released due to protein degradation and the decrease in pH level at the later stage of composting was caused by the volatilization of ammoniacal nitrogen and H+ released due to microbial nitrification process by nitrifying bacteria (32). The values of pH followed similar pattern as reported by Ponsá et al (33) and Cabañas-Vargas et al (34), rising progressively over the first few days; further decreased steadily after that point and remained fairly stable with values between 6 and 7. The pH in all the vessels was in range with WHO, GOTS and Iranian National Standards (Table 4).

Change in the TOC content during the composting period is shown in Figure 3. The content of organic carbon decreased as the decomposition progressed. Initially, the amount of the TOC were 27.17%, 26.6% and 26.43%, which then reduced to 24.01%, 25.02% and 25.78%, respectively in R1, R2 and R3. Around 17.25% of the available carbon in R1 and 2.5% in R2 and 11.36% in R3 were utilized by microorganism as a source of energy.

This finding corresponds with the findings of Wong et al (5) who suggested that such a decrease in organic carbon at the end of composting process may be due to active microbial decomposition of organic substrates. The highest reduction rate was found in vessel R1 (17.25%) suggesting higher metabolic activity of microorganisms. A possible reason for this is that in vessel R1, the ratio of sludge to bulking agent was higher when compared with the other vessels. The low organic carbon contents of vessel R1 indicates the maturity of compost in this vessel which corresponds with the findings of Garcia et al (35) and Hernández et al(13), who studied the evolution of organic, chemistry and biological parameters in composting process and concluded that the percentage of carbon fraction declined due to mineralization. The findings of this study showed that the final organic carbon content in all the vessels was in the range of GOTS, WHO and Iranian National Standards.

Total nitrogen contents in all the vessels increased within 23 days of composting period due to the net loss of dry mass in terms of carbon dioxide, as well as the water loss by evaporation due to heat evolution during oxidization of organic matter (36). Nitrogen fixing bacteria might also contribute to the increase in total nitrogen in the later stage of composting. Nitrogen may be lost due to escape of ammonia (37) or other volatile nitrogenous gases from the compost material to the atmosphere. Vessel R1 contained significantly higher total nitrogen than vessels R2 and R3 (1.98%) throughout the composting process. Total nitrogen behaved in a similar manner in all vessels as observed by Sánchez-Monedero et al (37). The findings of the current study concur with the findings of Wong et al (5) and Bishop and Godfrey (38). Therefore, all the vessels were primarily stabilized after 23 days, but vessel R3 showed better stabilization, which contains the lowest nitrogen content.

Phosphorus in organic material is released by a mineralization process consisting of microorganisms. Inorganic phosphorus negatively charged, reacts readily with positively charged iron (Fe), aluminum (Al), and calcium (Ca) ions to form relatively insoluble substances. When this occurs, phosphorus is considered fixed or tied up. In this regard, phosphorus does not behave like nitrate (NO_3-N), which also has a negative charge but does not form insoluble complexes (18). The final total phosphorus of vessel R3 (0.71%) was higher than that of R1 (0.67%) and R3 (0.31%), respectively. With regards to the total phosphorous, no changes was observed in all the vessels in the pre- and post-composting process. Total phosphorous in vessels R2 and R3 (0.31% and 0.71%) are within the WHO range (0.3% to 3.5%).

The change in C/N ratios shows the achieved organic matter decomposition and stabilization during composting. The decomposition of organic matter was conducted by living organisms, which utilize the carbon as energy source and nitrogen for building cell structures. The C/N ratio decreased rapidly from initial values of 30 to 13.8, 17.99 and 20.65 in R1, R2 and R3, respectively after 23 days of composting (Figure 5). The excess carbon tends to utilize nitrogen in the soil to build cell protoplasm, if the C/N ratio of compost is more. This results in the loss of nitrogen in the soil and is known as robbing of nitrogen in the soil. On the other hand, if C/N ratio is too low, the resultant product does not help improve the structure of the soil. It is therefore desirable to control the process so that the final C/N ratio is less than or equal to 20 (39). Thus, it can be concluded that compost from all the vessels were primary stabilized after 23 days of composting, similarly as Huang et al (36) and Varma and Kalamdhad (18), but are below the optimal C/N ratio of 25. It is suggested that this amount of bulking agent does not require further nitrogen to obtain a compost mixture of C/N ratio between 20 and 25. Although, the C/N ratio cannot be used as an absolute indicator of compost maturation due to the large differences that is dependent on the initial compounds (5); a value around or below 20 could be considered satisfactory (39). It is only the values of C/N ratio that are not sufficient to say that organic compost is mature, or that, the composting process has reached the maturation phase, because the maturation phase is related to the synthesis of humic substances.

The MPN of the total and fecal coliforms in different stages of composting process decreased. It is suggested that reduction in MPN of all the vessels may result from the occurring thermophile phase during composting process. However, this phase occurred with delay in vessel R2 when compared with the other 2 vessels, in accordance with pH changes (Figure 2). The final compost product is classified into classes A and B according to EPA standard (16). In class A, there should be <1000 MPN and in class B $<2 \times 10^6$ MPN fecal coliforms/g of compost. In this study, all the vessels with MPN less than 1000 fecal coliforms per g are were considered to be in class A, therefore, the final product of composting can be used safely as a soil amendment in agriculture.

Conclusion

Composting of green waste with dewatered sludge in R3 and R1 produced higher final total phosphorus and total nitrogen when compared with other vessels after 23 days of composting. Lower pH and nitrogen, indicated its less phytoxicity effects on the growth of plant if applied to the soil. In addition, composts with lower microbial activity indicated that the compost was ready for usage as a soil conditioner. Therefore, it can be invented that composting of green waste with dewatered sludge in ratio 1.5:1 is more efficient in rotary drum composter. It is concluded that the final product of composting of dewatered and digested sludge and green waste in Ahvaz, Iran have good microbial quality of level A according to EPA classification and is acceptable according to WHO, GOTS and Iran National Standards with regards to the most physical and chemical parameters, therefore, it can be used in farmland and agriculture as a soil fertilizer and conditioner.

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Ethical issues

We certify that all data collected during the study is presented in this manuscript and no data from the study has been or will be published separately.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

NJHF conceived and designed the study. BM, MA, RAB, HB and AM did the lab work and MR and AZJ performed literature search and wrote the manuscript. All authors participated in the data acquisition, analysis and interpretation. All authors critically reviewed, refined and approved the manuscript.

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